

Comparative Analysis on the Ballistic Performance of Planar Soft Armours Against a Common Projectile With Different Jacket Alloys Through Binary Regression Analysis

E. Gavelda¹, R. Burris¹, M. Denhart¹, J. Gardner², A. Gibson¹, and M. Greene²

¹*Energetic Test Labs, 5055 S. 33rd Street, Phoenix, 85040 AZ, USA, eric@energetictestlabs.com*

²*National Institute of Justice, 710 7th Street, Washington DC, 20531, USA*

Abstract. The Remington 9mm Luger 124 grain FMJ ammunition has a longstanding and widespread history of use by the body armour industry and is engrained as a standard ammunition for the assessment of handgun ballistic protection levels for law enforcement. Specifically, in the National Institute of Justice (NIJ) Compliance Testing Program (CTP) this applies to NIJ armour type II and IIIA in NIJ 0101.06 and the future HG1 and HG2 protection levels in NIJ 0101.07 and NIJ 0123.00. To date a copper jacket projectile has been the only type produced by Remington and utilized by the NIJ, but recently Remington has made a production change in the jacket alloy from Copper to Brass for part number 23558. To better understand the change in the jacket alloy versus terminal ballistics, a test plan has been created to evaluate the performance of copper jacketed and brass jacketed variants of the Remington 9mm Luger 124 grain FMJ ammunition against planar-soft armour panels of two commonly used ballistic materials. The approach uses established methods to assess and compare the performance of projectiles at 0° angle of incidence using statistical regression analysis and confidence intervals to evaluate potential changes in the bullets penetration power against soft body armour systems. This paper details a test plan for evaluation of changes of bullet jacket alloys, results of a binary regression analysis of V_{50} , V_{20} , and V_0 testing of the jacket alloys against standard soft armour shoot packs of aramid and UHMWPE, and provides ballistic results compared in graphical form using S-Curves followed by suggested further refinement to the test method and analysis for future evaluation of changes in testing ammunition.

1. REMINGTON 9MM LUGER AMMUNITION

The Remington 9mm Luger 124 grain full metal jacket (FMJ) cartridge has long served as a benchmark round within the body armour industry, widely adopted for assessing handgun ballistic protection levels in law enforcement applications. Its role is particularly established within the National Institute of Justice (NIJ) Compliance Testing Program (CTP), where it is designated for evaluating NIJ armour types II and IIIA under NIJ Standard 0101.06, as well as the forthcoming HG1 and HG2 protection levels under NIJ 0101.07 and NIJ 0123.00. Historically, this ammunition has featured a copper-jacketed projectile exclusively. However, a recent manufacturing change by Remington—specifically for part number 23558—replaces the traditional copper jacket with a brass alloy. To assess the potential impact of this material substitution on ballistic performance, a comparative test plan was developed to evaluate both copper- and brass-jacketed variants against soft body armour panels composed of two widely used materials. Using standardized test methods, the study focuses on 0° angle-of-incidence impacts and employs statistical regression analysis with confidence intervals to determine whether the change in jacket composition affects the projectile's penetration capability.

This test plan provides the procedures and requirements to evaluate the terminal ballistic performance of copper jacketed and brass jacketed variants of the Remington 9mm Luger 124 grain FMJ (Full Metal Jacket) ammunition against planar-soft armour panels of two commonly used ballistic materials. The approach used establishes a method to assess and compare the performance of projectiles at 0° angle of incidence using statistical regression analysis techniques over a broad range of velocities, relative to the threat protection level test requirements in the National Institute of Justice (NIJ) NIJ 0101.07 [1] and NIJ 0123.00 [2].

The Remington 9mm Luger 124 grain FMJ ammunition has a longstanding and widespread history of use by the body armour industry and is engrained as a standard ammunition for the assessment of handgun ballistic protection levels for law enforcement. Specifically, in the NIJ standard this applies to NIJ II and IIIA (in NIJ 0101.06) and the future HG1 and HG2 (in NIJ 0101.07 and NIJ 0123.00). The copper variant of the projectile has been the only type utilized by the NIJ. Figure 1 provides a visual comparison of the copper and brass projectiles, and Table 1 compares the physical properties of the two jacket variants.



Figure 1. Sample projectiles taken from lots used in this evaluation of the copper (left), and brass (right) variants of the Remington 9mm Luger 124 grain FMJ ammunition

From a sampling of 30 projectiles for each variant, physical characteristics of length, diameter and weight were measured and documented. Table 1 summarizes those measurements. The Brass variant showed a small average decrease in length and corresponding weight. No difference was measured in diameter.

Table 1. Physical measurements and weights from 30 samples of each ammunition projectile jacket type used in this evaluation

Sample	Copper Jacket			Brass Jacket		
	Length (mm)	Diameter (mm)	Weight (grain)	Length (mm)	Diameter (mm)	Weight (grain)
Min.	14.98	8.9	124.96	14.55	8.93	123.52
Max.	15.28	8.98	126.15	14.92	8.99	124.24
Average	15.12	8.96	125.34	14.73	8.96	123.85
Delta	-	-	-	-0.39	0.00	-1.48
St. Dev.	0.085	0.017	0.371	0.086	0.019	0.205

2. TEST PROTOCOL AND ARMOuR SAMPLES

During ballistic limit testing, test articles are repeatedly subjected to projectiles across a range of impact velocities. This range is carefully balanced to ensure the occurrence of both complete and partial penetrations. The primary objective is to determine the ballistic limit, specifically the V_{50} value, which represents the impact velocity at which there is a 50% probability of complete penetration. Several established methodologies exist for conducting such tests and calculating V_{50} . This metric is particularly useful for determining the specific energy absorption of materials, facilitating comparisons of ballistic efficiency across different armour systems. Additionally, V_{05} , defined as the impact velocity at which the probability of complete penetration is only 5%, serves as a more conservative measure for assessing the safety margin of body armour. To estimate V_{50} and V_{05} , a logistic regression method will be used as detailed in work performed by C. Boettger [3], which involves applying linear regression to the logarithm of the odds of complete penetration.

2.1 Regression Analysis Test Protocol

Three subtests shall be performed for each projectile and test panel combination (i.e. “test pair”) at 0° angle of incidence and a fourth subset is planned at 30° and 45° angles of incidence. Data from all testing performed at 0° angle of incidence for each test pair will be combined for statistical regression analyses and comparison, utilizing a total of 160 shots per test pair.

- V_{50} Ballistic Limit: This test produces point estimates of the V_{50} ballistic limit for each test panel at 0° angle of incidence using the 3x3 up-down method. Four panels, with 16 shots per panel, will be tested for 64 data points.
- Velocity Sweep Across V_{20} : This test utilizes data from the V_{50} ballistic limit subtest to calculate the V_{20} ballistic limit for each test pair. Testing shall be performed at 0° angle of

incidence from 60 meter per second (m/s) below, to 60 m/s above the V_{20} . Four panels, with 16 shots per panel, will be tested for 64 data points.

- V_0 HG1 and HG2 Ranges: Testing shall be performed at 0° angle of incidence at velocities below, and in accordance with the NIJ HG1 and NIJ HG2 protection levels in NIJ Standard 0123.00. Two panels, with 16 shots per panel, will be tested for 32 data points.
- Angled Incident Shots: Future testing planned to be performed at 30° and 45° angles of incidence at velocities in accordance with the NIJ HG1 and NIJ HG2 protection levels in NIJ Standard 0123.00.

The test panels used in this evaluation have an estimated V_{50} ballistic limit of approximately 488 m/s, which is 40 m/s above the NIJ HG2 reference velocity in NIJ Standard 0123.00 for the Remington 9mm Luger 124 grain FMJ. Figure 2 provides representation of the velocity ranges, or estimated velocity ranges, for each subset in relation to the test type and NIJ soft armour protection levels.

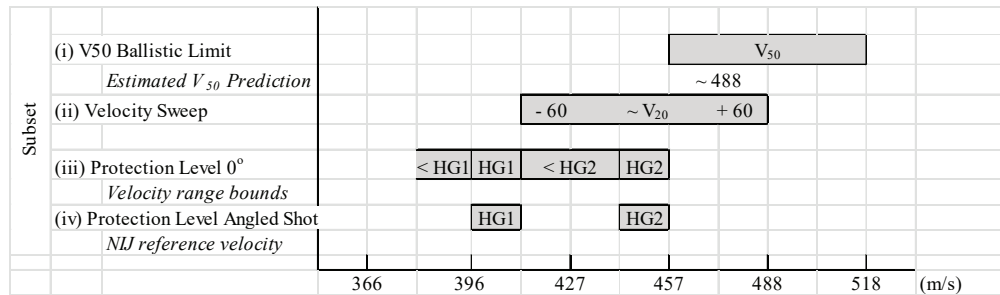


Figure 2. Test protocol and velocity range for each test subset

2.2 Armour Samples

Copper and Brass projectile jacket variants of the Remington 9mm Luger 124 Grain FMJ ammunition shall be evaluated against two soft armour panel types: woven aramid, and unidirectional (UD) cross-ply ultra-high-molecular-weight polyethylene (UHMWPE). All soft armour samples were built in planar construction, 380 mm by 380 mm dimensions with 100 mm corner diagonal stitches and a ballistic nylon cover. Test panel construction and the four test pairs, i.e. combinations of projectile type and test panel type, are documented in Table 2.

Table 2. Combination of projectile and armour sample type in this evaluation

Test Panel Type	Test Panel Construction	Projectile Jacket Type	Test Pair
Aramid (A)	34 Plies 600d KM2 Kevlar 34 x 34 Plain Weave 0.48 g/cm ²	Copper (C)	Aramid vs. Copper (AC)
		Brass (B)	Aramid vs. Brass (AB)
UHMWPE (P)	28 Plies Dyneema SB31 Unidirectional Cross Ply 0.37 g/cm ²	Copper (C)	UHMWPE vs. Copper (PC)
		Brass (B)	UHMWPE vs. Brass (PB)

2.3 Shot Pattern

Each soft armour panel was shot 16 times evenly placed on the 380 mm by 380 mm panel staggering the shots by at least a diameter off line from prior horizontal and vertical shots. Figure 3 below displays the shot pattern for the test plan.

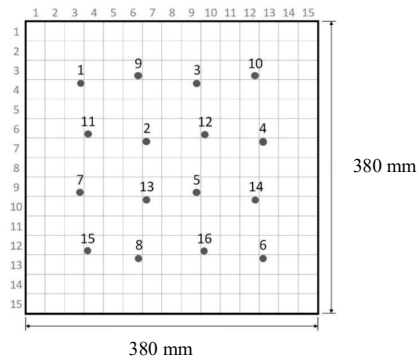


Figure 3. Shot pattern and order

3. BALLISTIC RESULTS

For each test pair the logistic regression analysis was run after the first test subset (V_{50} Ballistic Limit) to estimate the V_{20} to set up the second test subset velocity sweep for each test pair. After the three subset tests were completed, the logistic regression was performed again, and each test panel type was compared against each projectile test type using a 95% confidence level over the curve.

3.1 Aramid

The logistic regression analysis and s-curves, Figure 4, are the results of 160 shots taken on aramid test panels against the copper jacket 9 mm round and brass jacket 9 mm round. From these curves the V_{50} probability of penetration is estimated to be 490.7 m/s for the copper jacket and 490.2 m/s for the brass jacket. The new brass jacket has a decrease in V_{50} of only 0.10% than the original copper jacket.

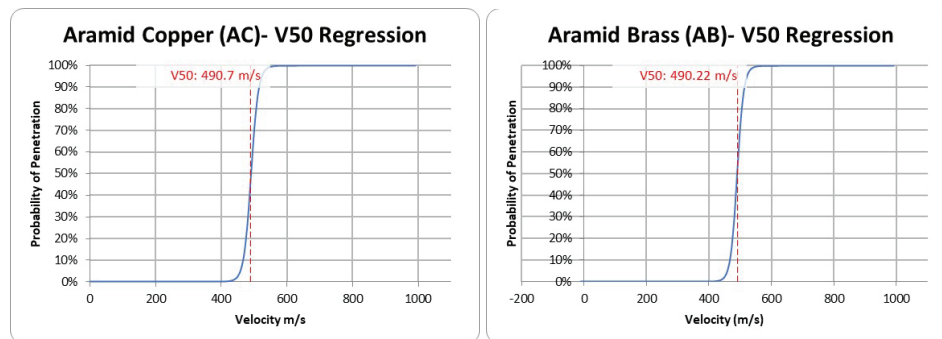


Figure 4. Logistic regression S-Curve for Aramid test panels versus copper and brass jacket 9 mm

Ballistic armour with steeper S-curves is most desirable since the confidence bounds at different V_{xx} will be narrower, increasing confidence in the measured probability. At lower probabilities like V_{05} , an increase in shot sampling is needed to also help decrease these confidence bounds. The three step test protocol covering the V_{50} range, sweeping across the V_{20} range and testing across the NIJ 0101.07 V_0 range was specifically designed to increase shots at these velocity ranges. Figure 5 compares the aramid test panels and includes a 95% confidence bound in response to each type of jacket to help calculate these confidence bounds.

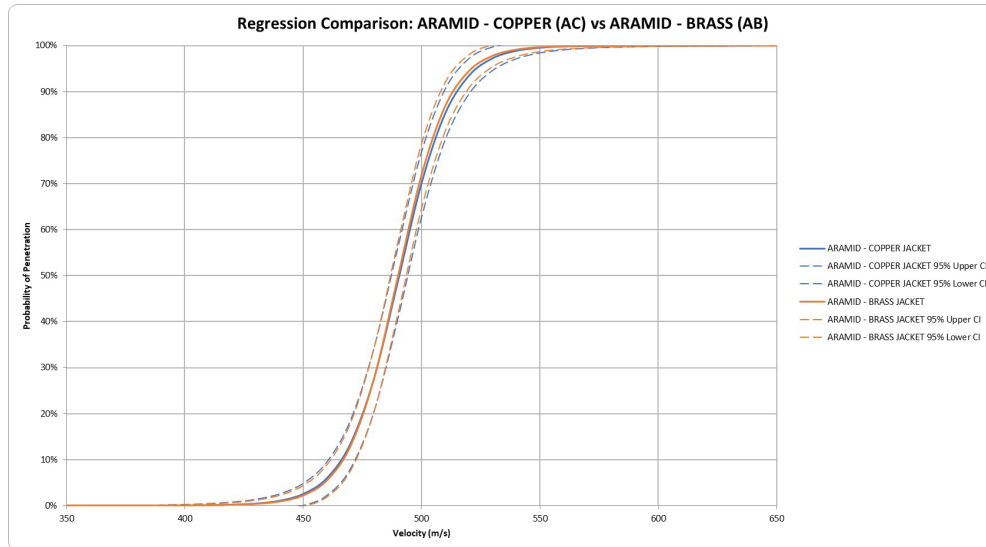


Figure 5. S-curve with 95% confidence interval for aramid versus copper and brass jackets

From the S-curves with 95% confidence intervals it can be seen both curves generated for each jacket fall within the 95% confidence interval of each other at the V_{50} and V_{05} . The range of confidence intervals did increase at the lower V_{05} versus V_{50} to 14.7 m/s from 6.52 m/s as seen in table 3. These results suggest the jacket type does not influence ballistic penetration against standard aramid test panels.

Table 3. Velocity at various probability of penetration percentages for aramid test panels versus copper and brass jackets and 95% confidence bound of V_{50} and V_{05}

	Aramid Copper (AC)	95% Lower Limit	95% Upper Limit	Range	Aramid Brass (AB)	95% Lower Limit	95% Upper Limit	Range	% Increase
V_{60} , m/s	495.2				494.5				-0.14%
V_{50} , m/s	490.7	487.3	494.1	6.8	490.2	487.0	493.5	6.5	-0.10%
V_{40} , m/s	486.2				485.9				-0.06%
V_{20} , m/s	475.3				475.6				0.06%
V_{05} , m/s	458.1	450.3	465.7	15.4	459.2	451.8	466.5	14.7	0.23%

3.2 Ultra High Molecular Weight Polyethylene

The logistic regression analysis and s-curves, Figure 6, are the results of 160 shots taken on UHMWPE test panels against the copper jacket 9 mm round and brass jacket 9 mm round. From these curves the V_{50} probability of penetration is estimated to be 510.5 m/s for the copper jacket and 523.9m/s for the brass jacket. The new brass jacket has an increase in V_{50} of 2.58% than the original copper jacket.

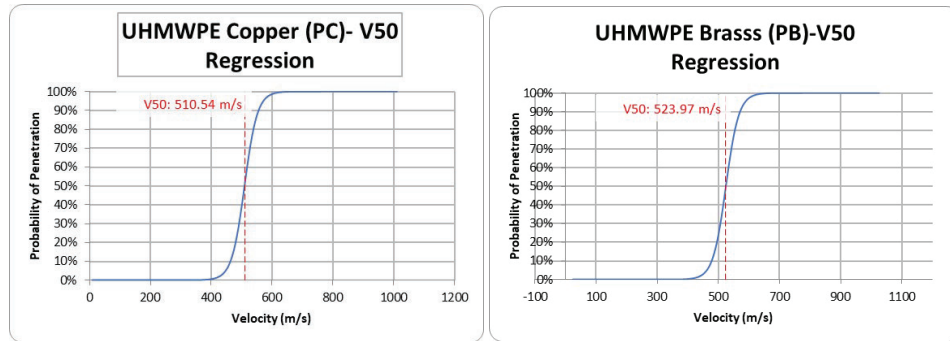


Figure 6. Logistic regression S-Curve for UHMWPE test panels versus copper and brass jacket 9 mm

As mentioned earlier, ballistic armour with steeper S-curves is most desirable since the confidence bounds at different V_{xx} will be narrower, increasing confidence in the measured probability. From figure 7 comparing the UHMWPE test panels and the 95% confidence bound in response to each type of jacket shows a less steep S-curve than the prior aramid test panel results but also a higher V_{50} of 18- 30 m/s for both types of jackets. The higher performing UHMWPE fibers even at 25% less areal density than aramid still had a higher V_{50} than the aramid packs leading to two major variables that could cause an excess in variability: lower areal density and higher V_{50} starting point compared to the NIJ 0101.07 V_0 .

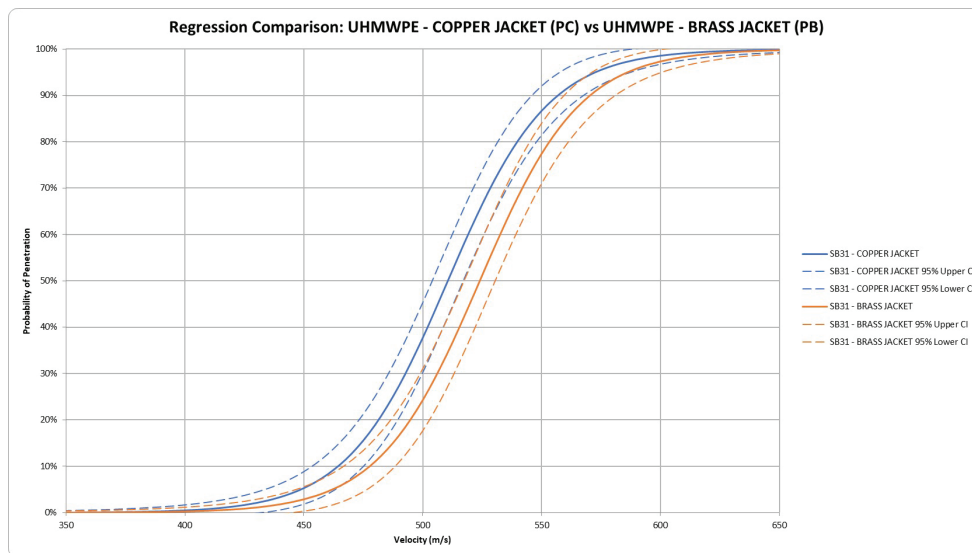


Figure 7. S-curve with 95% confidence interval for UHMWPE versus copper and brass jackets

From the S-curves with 95% confidence intervals it can be seen the curves generated for each jacket do not fall within the 95% confidence interval of each other at the V_{50} and V_{05} . The V_{50} of the brass jacket is 18 fps above the upper limit for the brass jacket and just 1 fps above the upper limit for the V_{05} . The range of confidence intervals did again increase at the lower V_{05} versus V_{50} to 29.4 m/s from 13.0 m/s as seen in table 3, with both ranges being higher than seen in the heavier aramid test pack. These results suggest the jacket type is slightly influencing the ballistic penetration against standard UHMWPE test panels. At the lower areal density of the UHMWPE test packs (0.37 g/cm² versus 0.48 g/cm² of the aramid) the manufacturer expected the variability of the V_{50} testing to be higher with that factor alone. This variable could be investigated further to better understand if and to what extent the relationship of armor areal density has on the confidence interval spread.

Table 4. Velocity at various probability of penetration percentages for UHMWPE test panels versus copper and brass jackets and brass jackets and 95% confidence bound of V_{50} and V_{05}

	UHMWPE Copper (PC)	95% Lower Limit	95% Upper Limit	Range	UHMWPE Brass (PB)	95% Lower Limit	95% Upper Limit	Range	% Increase
V_{60} , m/s	519.8				532.5				2.45%
V_{50} , m/s	510.8	503.5	518.7	15.2	524.0	517.5	530.5	13.0	2.58%
V_{40} , m/s	501.7				515.4				2.73%
V_{20} , m/s	479.9				494.7				3.10%
V_{05} , m/s	445.1	425.4	461.4	36.0	461.9	447.1	476.6	29.4	3.77%

4. CONCLUSIONS

Logistic regression analysis has been shown as a useful tool to be utilized for evaluation of ballistic penetration performance when a material or design change occurs within a specific ammunition type. With an adequate sample size and range of velocities spreading from the V_0 range through the V_{50} estimate of the armour sample, the S-curve can be analysed at the 95% confidence interval to understand if the ballistic penetrating power of ammunition changes will have a more or less severe effect on standard armour samples.

Future work should include investigating effect on areal density of the armour test pack versus change in 95% confidence bound at V_{50} and V_{05} using the same armour material to better define standard materials and areal densities that are most repeatable for evaluating changes in ammunition materials and design.

Acknowledgments

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References

- [1] Ballistic Resistance of Body Armor, NIJ0101.07, NJC 307346, October 2023.
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